J. Perinat. Med.
17 (1989) 279

Doppler sonographic evaluation of exercise-induced blood flow velocity and waveform changes in fetal, uteroplacental and large maternal vessels in pregnant women

Hans Baumann, Albert Huch, and Renate Huch

Department of Obstetrics, Perinatal Physiology Unit, University Hospital of Zurich, Zurich, Switzerland

1 Introduction

Initial responses to exercise are characterised by an increase in cardiac output, heart rate and stroke volume, systolic blood pressure, oxygen consumption, respiratory minute volume and a redistribution of blood flow: there is an increase of blood flow to the working muscles and a decrease in renal, splanchnic, non-working muscles and in skin circulation [19, 32]. The question as to whether or not uterine blood flow is affected by the reduction of splanchnic blood flow has been investigated in only a few studies in the human. By measuring the clearance time of radioactive sodium (Na^{24}) injected into the uterine muscles, a decrease in uterine blood flow during short-term bicycle exercise was found [26]. Recent studies using the Doppler technique for assessing the uteroplacental blood flow did not detect blood flow velocity changes after maternal exercise [25, 34]. The aim of this study was the evaluation by Doppler sonography of blood flow velocity and waveform changes after exercise not only in the uteroplacental circulation, but also in fetal (umbilical) and large maternal vessels (femoral artery and vein, carotid artery). To the best of our knowledge the relation of uteroplacental, femoral and cerebral blood flow after leg exercise had not been investigated previously by the Doppler technique in pregnant women.

2 Material and methods

Thirteen women (8 primiparous, 5 multiparous) gave their informed consent to participate in the study. The median age was 30 years (range 23 to 40), median weight 70 kg (range 57 to 108), median prepregnancy weight 57 kg (range 48 to 94) and median height 166 cm (range 153 to 181). All women were healthy, untrained, nonsmokers with uncomplicated pregnancies. Median gestational age at the time of the exercise test was 38 weeks (range 36 to 40), at the time of delivery 40 weeks (range 39 to 41) and the median interval between the exercise test and delivery was 14 days (range 1 to 31). All women gave birth to healthy children with Apgar scores at 5 minutes of ≥ 8, normal umbilical cord pH (median value 7.31, range 7.21 to 7.41) and birthweights above the 10th percentile (median weight 3370 g, range 2910 to 3950).

The exercise test was performed in a sitting position on a bicycle ergometer connected to a chair seat. During cycling, the back rest was 60 degrees above the horizontal. For the Doppler measurements the back rest was 40 degrees above the horizontal and the patient in a left-semirecumbent position to avoid a hypotensive syndrome.

Doppler measurements were performed with a duplex system (Acuson Model 128, Acuson Computed Sonograph, Mountain View, California, USA). Details of the pulsed Doppler equipment and of the technique of the examination of large maternal vessels have already been described [3]. In the femoral and carotid arteries, peak velocities (systolic and end-diastolic, and for the femoral artery also postsystolic – see figure) were calculated over an average of 4–6 cardiac cycles. Time average of mean velocity (TAV mean) was calculated 3–5 times over 5 seconds for the arterial vessels and over 8 seconds in the femoral vein. The femoral vein diameter was determined from several randomly made B-mode images in a longitudinal scan. Diameter measurements of femoral and carotid arteries were made by measuring the vessels' systolic and diastolic diameters with the M-mode technique in a longitudinal scan from 5 different subjects of comparable gestational age since Doppler and vessel diameter measurements could not both be carried out simultaneously.

Uteroplacental circulation was examined on the placental side. From the uteroplacental vessels (4 to 6 cardiac cycles) and the umbilical artery (8–10 cardiac cycles), the resistance index (RI) [29] and pulsatility index (PI) [14] were analysed after transfering the stored Doppler signal into a Doptek spectrum analyser (Doptek Ltd, England).

Maternal heart rate was measured continuously by electrocardiogram (Cardiorespirograph Hellige, Freiburg) and systolic and diastolic blood pressures on the left arm automatically at 20-second intervals (Sphygmomanometer Dinamap, Applied Medical Research, Tampa, Florida). Fetal heart rate was calculated from the Doppler singal when analysing the umbilical artery.

The work load was 100 Watts during 3 minutes with a pedalling rate of 60 cycles per minute. Per patient, 5 exercise tests with this work load were performed in order to examine each particular vessel as soon as possible after exercise. The sequence of vessel examination and parameters analysed are shown in Table I. Values before and after exercise were tested using the Wilcoxon signed rank test. A p value < 0.05 was considered significant.

3 Results

3.1 Maternal heart rate and blood pressure

In each exercise test, median heart rate increased by about 50% (table I). There was a slight increase in pre-exercise heart rates throughout the examination. Both systolic and diastolic blood pressures increased after each exercise test (table I).

Table I. Sequence of vessel examinations, parameters analysed, and maternal heart rates and blood pressures before and after the five exercise tests. Numbers are median and range.

	Exercise tests				
	first	second	third	fourth	fifth
Vessel examined	Femoral vein	Femoral artery	Carotid artery	Uteroplacental vessels	Umbilical artery
Parameter	Mean velocity	Mean velocity, peak velocities	Mean velocity, peak velocities Resistance Index, Pulsatility Index	Resistance Index, Pulsatility Index	Resistance Index, Pulsatility Index
Maternal heart rate					
preexercise	90 (65–100)	95 (65–100)	100 (75–110)	100 (90–115)	103 (80–110)
postexercise	150 (135–160)	150 (135–170)	155 (140–170)	160 (145–170)	158 (145–170)
Blood pressure, systolic (mmHg)					
preexercise (median, range)	109 (99–132)	121 (99–134)	114 (101–139)	113 (103–131)	119 (108–128)
postexercise	132 (114–152)	137 (112–153)	139 (119–151)	138 (119–161)	138 (117–167)
Blood pressure, diastolic (mmHg)					
preexercise	69 (57– 81)	67 (57– 83)	69 (46– 83)	65 (52– 85)	67 (64– 75)
postexercise	76 (66– 87)	75 (62– 86)	77 (68– 91)	74 (65– 91)	74 (63– 97)

3.2 Carotid artery

Median heart rate at the time of analysing the carotid artery velocity and waveform was 117 bpm (range 100 – 133). Mean blood flow velocity did not change (table II). The increase of systolic and decrease of end-diastolic velocities led to an increase in resistance and pulsatility indices. Before exercise, the median systolic diameter was 6.1 mm (range 5.7 to 6.4), the median diastolic diameter, 5.3 mm (range 5.2 to 5.8); after exercise the median systolic diameter was 6.3 mm (5.8 to 6.4), and the median diastolic diameter 5.4 mm (range 5.3 to 5.8). The differences are not statistically significant.

3.3 Femoral artery

At the time of analysing the femoral artery blood flow velocity and waveform, the maternal heart rate was 125 bpm (range 98 to 131), and the mean velocity was still 10 times higher than before exercise (table II). Systolic and end-diastolic velocities increased significantly (figure 1). Postsystolic flow velocity, which was reversed before exercise, became positive. The median systolic diameter was 7.9 mm (range 7.5 to 8.2) before and 7.8 mm (range 8.2 to 8.1) after exercise. The median diastolic diameter was 7.4 mm (range 6.9 to 7.7), respectively 7.3 mm (range 6.5 to 7.6).

3.4 Femoral vein

Mean velocity immediately after exercise was three times higher compared to the pre-exercise value. After exercise, the mean velocity returned quickly to pre-exercise levels: the median value after 1 minute was 0.15 m/s, after 2 minutes 0.09 m/s. The median diameter before exercise was 13.5 mm (range 10.9 to 15.8), after exercise 15.2 mm (range 12.4 to 16.2).

3.5 Uteroplacental vessels

Median heart rate at the time of waveform analysis was 133 bpm (range 114 to 167). Neither RI nor PI showed changes after the exercise test.

Table II. Median values and range of blood flow velocities and/or indices in the maternal carotid artery, femoral artery and vein, uteroplacental and fetal vessels before and after exercise.

Vessel and parameter	before exercise		after exercise		p value
	median	range	median	range	
Carotid artery					
Systolic maximum velocity (m/s)	0.91	0.69 – 1.25	1.15	0.84 – 1.32	<0.005
Enddiastolic maximum velocity (m/s)	0.23	0.17 – 0.29	0.16	0.11 – 0.30	<0.005
Mean velocity (m/s)	0.19	0.18 – 0.27	0.20	0.16 – 0.26	ns
Resistance Index	0.76	0.66 – 0.83	0.80	0.66 – 0.88	<0.005
Pulsatility Index	2.10	1.38 – 3.04	2.86	1.82 – 3.44	<0.01
Femoral artery					
Systolic maximum velocity (m/s)	0.85	0.53 – 1.25	2.16	1.81 – 2.86	<0.002
Postsystolic velocity (m/s)	–0.25	–0.53 – (–)0.16	0.86	0.58 – 1.36	<0.002
Enddiastolic maximum velocity (m/s)	0.00	–0.08 – (+)0.11	0.76	0.46 – 1.06	<0.002
Mean velocity (m/s)	0.09	0.04 – 0.28	0.95	0.58 – 1.44	<0.001
Femoral vein					
Mean velocity (m/s)	0.06	0.05 – 0.09	0.17	0.12 – 0.29	<0.002
Uteroplacental vessels					
Resistance Index	0.40	0.27 – 0.55	0.39	0.26 – 0.55	ns
Pulsatility Index	0.64	0.48 – 0.98	0.69	0.40 – 1.06	ns
Umbilical artery					
Resistance Index	0.59	0.46 – 0.71	0.53	0.45 – 0.67	<0.01
Pulsatility Index	0.98	0.68 – 1.24	0.87	0.67 – 1.19	<0.02

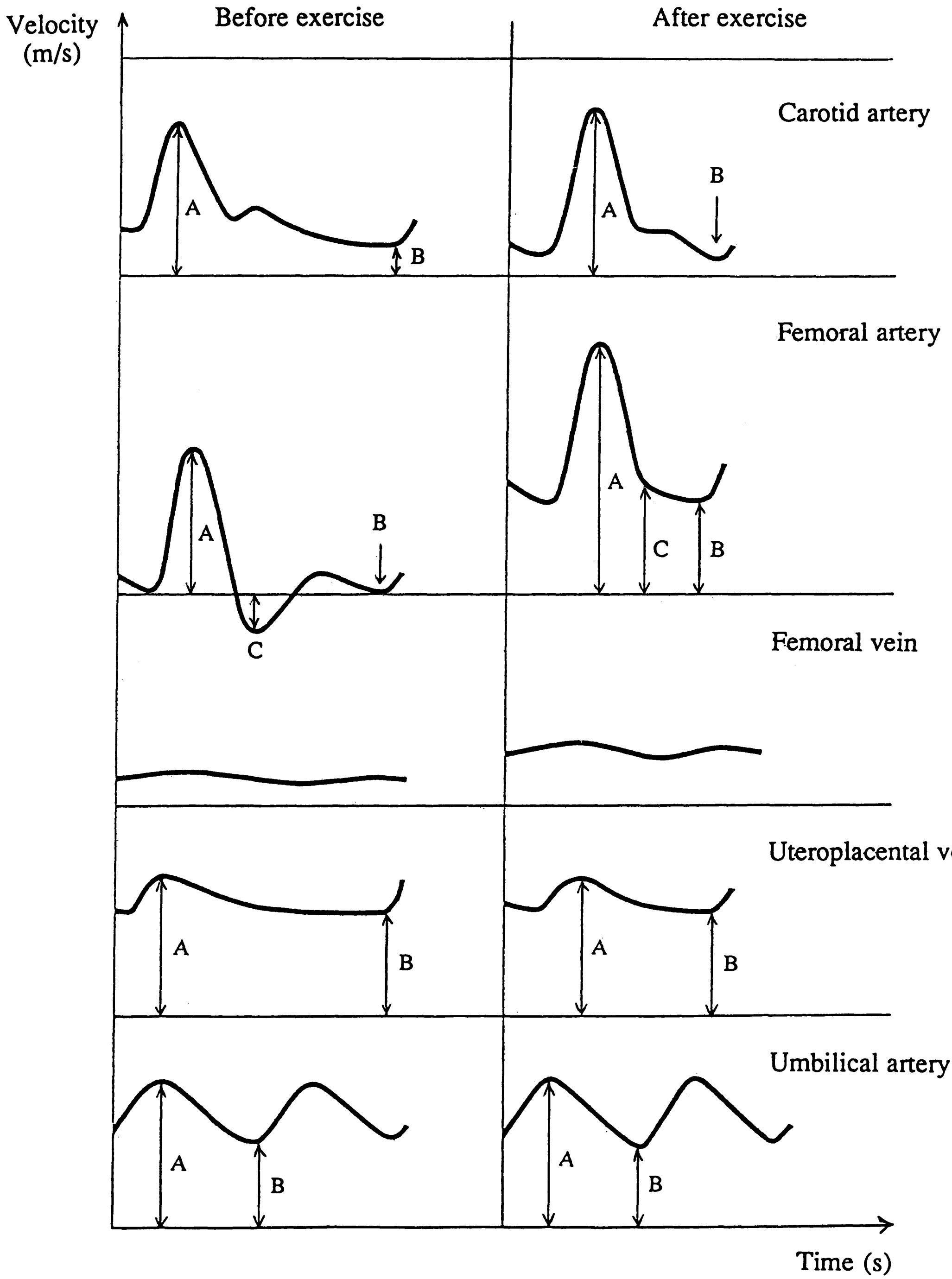

Figure 1. Schematic representation of blood flow velocity waveform changes in the examined vessels before and after exercise. A = systolic, B = end-diastolic, C = postsystolic.

3.6 Umbilical artery and fetal heart rate

Median fetal heart rate before exercise was 133 bpm (range 114 to 166), after exercise also 133 (range 114 to 167). Both RI and PI showed a slight yet significant decrease.

4 Discussion

In this study each woman underwent five cycling exercise tests. After each test, one particular vessel was examined in a defined sequence. This procedure was chosen because it was our aim to achieve a Doppler sonographic examination of a vessel as soon as possible after the end of exercise. This can present difficulties even for experienced researchers using a sophisticated duplex system such as Acuson 128, which allows simultaneous recording of Doppler shift and B-mode imaging and thus control of correct positioning of the sample volume and optimal angle adjustment. In this way maternal vessels were able to be examined with heart rates still above pre-exercise levels.

All participating women had uncomplicated pregnancies and gave birth to healthy children. At rest, blood flow velocity waveforms from the umbilical artery and uteroplacental vessels described by the resistance index (RI) [29] and the pulsatility index (PI) [14] were within normal limits for gestational age [3, 5, 11, 16, 36]. Each exercise test resulted in a significant increase of the maternal heart rate by more than 50% of the median value compared with the pre-exercise value. Median peak heart rate at the end of exercise corresponds approximately to 60% of Vo_2 max [2]. Median systolic and diastolic blood pressures increased. In nonpregnant adults, systolic blood pressure and heart rate increase with increasing work load and duration of exercise, whereas diastolic blood pressure remains unchanged [32]. In general, pregnant women show the same cardiovascular responses [1, 30, 37]. However, an increase of diastolic blood pressure was also noticed in another study [28].

In our study, exercise-induced blood flow velocity and waveform changes were greatest in the femoral artery. A marked increase was found in mean velocity, systolic and enddiastolic peak velocities as well as a disappearaeance of postsystolic reverse flow and a reversal to a positive flow. These blood flow velocity changes correlate with physiologic responses to exercise and in particular to leg exercise [23, 31, 35]. Working muscles require more energy and therefore an increased blood supply. Local metabolic factors lead to a vasodilatation of the resistance vessels of the muscles and a drop in peripheral vascular resistance. These changes in muscle blood flow lead to changes in blood flow velocity and waveforms. Basically, blood flow velocity changes are proportional to volume flow changes if the cross-sectional area of the vessel remains unchanged [12]. Measuring the diameter of the femoral artery with the M-mode technique, we could not find significant exercise-induced changes in femoral arterial diameter. It can thus be concluded that the increase of mean velocity correlates with the increase in leg blood flow.

Exercise-induced changes in myocardial contractility and stroke volume lead to an increase in systolic maximum velocity. The diastolic part of the blood flow velocity waveform is mostly influenced by peripheral vascular resistance or impedance. Both the increase in end-diastolic flow velocity and the reversal of postsystolic flow above the zero line are very sensitive indicators for the drop in peripheral vascular resistance.

To maintain diastolic filling and left ventricular cardiac output in exercise, venous return must be increased. In our study an increase was found both in the mean velocity and – though not significant – in the diameter of the femoral vein. Particularly in the standing and sitting positions, hydrostatic forces must be overcome by the venous return. In exercise, venous return is increased by an increase in venous tone through the stimulation of sympathetic nerves and by the abdomino-thoracic and muscle pumps [4, 24, 32]. The importance of the latter is underlined by our study, where we found a rapid decrease of venous flow velocity after the end of leg exercise.

In spite of the increase in femoral blood flow and a decrease in peripheral vascular resistance in the leg, we could not detect any changes in uteroplacental blood flow velocity using dimensionless and almost angle-independent indices such as RI and PI. These results are in agreement with two previous studies, in which uteroplacental blood flow was examined by the continuous wave Doppler technique. In one study, after stationary bicycle exercise, no change in blood flow expressed by the relation of systolic to end-diastolic maximum velocity (A/B Ratio) was found [25]. In the other study, treadmill exercise did not lead to a change in PI [34].

Indices such as RI and PI are dependent on heart rate and decrease with increasing heart rate. Considering the utero-placental blood flow velocity waveform, we believe that this effect is of minor importance yet it is striking that the results of these Doppler studies are not in agreement with a study in humans published in 1956 and with animal experiments. After radioactive sodium (Na^{24}) had been injected in the human uterine muscle, a decrease in clearance time indicating a decrease in uterine blood flow during exercise was noticed [26]. That study, however, has been criticised because it used a supine position. Although some animal experiments (ewes, goats) showed unchanged uterine blood flow [9, 27], most investigations showed a decrease in uteroplacental blood flow proportional to the level and duration of exercise [6, 7, 18, 20]. Although a drop in fetal Po_2 was noticed [6, 10, 21], certain compensatory mechanisms counteract the reduction in blood flow. These mechanisms include a redistribution a blood flow within the uterus favoring placental over non-placental blood flow [9, 18], an increase in uterine oxygen extraction and thus maintainance of uterine oxygen consumption [6, 7, 10] and an increase of hemoglobin and hematocrit within minutes after exercise begins, thus improving oxygen supply to the uterus [6, 29]. The latter mechanism also occurs in humans within a few minutes [15].

Rather difficult to interpret are our findings of a decrease in resistance in the umbilical artery. The decrease in PI and RI is small but significant. In animal experiments, umbilical flow either was reduced [7] or remained unchanged [21]. Fetal heart rate (FHR) did not change. Most of the exercise studies show either no changes or a slight increase in FHR after exercise [8, 22, 28].

The effects of exercise on cerebral blood flow have been investigated with different methods in non-pregnant adults. In most of these studies, no changes could be observed [13, 17, 33, 38]. Our findings of constant mean velocity and unchanged diameter are in agreement with these studies. We did, however, note an increase in cerebrovascular resistance, as another study also did [13]. Our results show that cerebral blood flow seems to be constant in pregnant women as well, despite an increase in systolic blood pressure.

In summary, the Doppler technique has made it possible to assess the effect of maternal exercise on fetal and maternal circulation. This study has shown that although leg exercise leads to a drop in vascular resistance and an increase in flow to the legs, uteroplacental blood flow seems to be unaffected after short-term moderate exercise.

Abstract

The aim of this study was the evaluation by Doppler sonography of blood flow velocity and waveforms in maternal (Femoral artery and vein, carotid artery, uteroplacental) and fetal (Umbilical artery) vessels before and after exercise. Thirteen healthy women with uncomplicated pregnancies (and outcomes) participated in the study between the 36th and 40th gestational week. Each proband underwent 5 exercise tests in a sitting position on a bicycle ergometer with a work load of 100 Watts during 3 minutes.

The Doppler measurements were performed with Acuson 128. In the femoral and carotid arteries, peak velocities (systolic and enddiastolic, and for the femoral artery also postsystolic) as well as the mean blood flow velocities were measured. Mean blood flow velocity was also measured in the femoral vein. For the measurements of the arterial diameters, the M-Mode technique, for the femoral vein diameter, the B-Mode technique was used. The uteroplacental and umbilical blood flow waveforms were analysed by the Resistance and Pulsatility Indices.

The maternal heart rate as well as systolic and diastolic blood pressures increased after each of the exercise tests. The mean blood flow velocity increased in both the femoral artery and vein while the vessel diameter remained constant. In the carotid artery, however, the velocity remained constant. An analysis of the velocity waveforms for the femoral artery showed in increase in the systolic and end-diastolic velocities as well as a reverseal of the post-systolic flow, where the velocity is negative in a state of rest. There was no change in the uteroplacental velocity waveform. In the carotid artery, an increase in resistance was seen, and in the umbilical artery a decrease.

Physical exercise leads to a redistribution of the blood flow. The blood flow to the working muscles increases at the expense of that to the inner organs. In animal experiments, uteroplacental blood flow decreases during exercise. In our study, however, there was no change found in the uteroplacental circulation although there was a sharp increase in the blood flow in the lower extremities. The absence of any changes in the fetal heart rate and umbilical blood flow velocity waveform indicates that there is no risk to the fetus. In summary, it can be said that no adverse effects on fetal and uteroplacental circulation were noted during moderate physical exercise in uncomplicated pregnancies.

Keywords: Doppler ultrasound, exercise, fetus, mother, pregnancy.

Zusammenfassung

Dopplersonographische Untersuchung von Blutflußgeschwindigkeit und Blutflußprofilen in mütterlichen und fetalen Gefäßen vor und nach körperlicher Belastung bei schwangeren Frauen

Ziel dieser Arbeit war die Untersuchung von Blutflußgeschwindigkeiten und Blutflußprofilen in mütterlichen (A. und V. femoralis, A. carotis, uteroplazentar) und fetalen (A. umbilikalis) Gefäßen mit der Dopplersonographie vor und nach einer körperlichen Belastung. 13 Frauen mit komplikationsloser Schwangerschaft und unauffälligem Schwangerschaftsausgang beteiligten sich zwischen der 36. und 40. Schwangerschaftswoche an der Studie. Jede Probandin unterzog sich 5 Belastungstests in sitzender Position auf einem Fahrradergometer mit einer Arbeitsleistung von 100 Watt während 3 Minuten.

Für die Doppleruntersuchungen wurde ein Acusongerät verwendet. In der A. femoralis und A. carotis wurden die maximalen Geschwindigkeiten systolisch und end-diastolisch, in der A. femoralis auch postsystolisch, sowie die mittlere Blutflußgeschwindigkeit gemessen. Die letztere wurde ebenfalls in der V. femoralis bestimmt. Die Messung der Gefäßdurchmesser erfolgte in den arteriellen Gefäßen mit der M-Mode, in der V. femoralis mit der B-Mode Technik. Die Blutflußprofile uteroplazentar und umbilikal wurden mit dem Resistance und Pulsatilitäts-Index analysiert.

Die mütterliche Herzfrequenz sowie systolischer Blutdruck stiegen nach der Belastung an. Die mittlere Blutflußgeschwindigkeit nahmen sowohl in der A. und V. femoralis bei konstantem Gefäßdurchmesser zu, blieb jedoch in der A. carotis unverändert. Die Analyse der Flußprofile ergab in der A. femoralis eine Zunahme der systolischen und end-diastolischen Flußgeschwindigkeit sowie eine Umkehr der postsystolischen Flußkomponente, die in Ruhe rückwärts läuft. Uteroplazentar blieben die Flußprofile unverändert. In der A. carotis zeigte sich eine Widerstandserhöhung, in der A. umbilikalis eine -verminderung.

Eine körperliche Belastung führt zu einer Blutumverteilung. Der Blutfluß nimmt in der arbeitenden Muskulatur u. a. auf Kosten der inneren Organe zu. Im Tierexperiment nimmt der uteroplazentare Blutfluß während einer Belastung ab. In dieser Untersuchung fanden sich jedoch keine Veränderungen in der uteroplazentaren Zirkulation, obwohl der Blutfluß in die unteren Extremitäten stark zunahm. Die Reaktion der fetalen Herzfrequenz sowie der umbilikalen Flußprofile lassen ebensowenig eine fetale Gefährdung vermuten. Zusammenfassend kann gesagt werden, daß auch bei mittelgradiger körperlicher Belastung in komplikationslosen Schwangerschaften keine Beeinträchtigung der fetalen und uteroplazentaren Zirkulation nachzuweisen ist.

Schlüsselwörter: Dopplersonographie, Fet, Mutter, Schwangerschaft.

Résumé

Evaluation par échographie doppler chez la femme enceinte de la vélocité sanguine et des modifications des ondes induites par l'exercice au niveau des vaisseaux fœtaux utéro-placentaires et maternels

L'objectif de cette étude est l'évaluation par échographie doppler de la vélocité sanguine et des ondes au niveau des vaisseaux maternels (artère, veine fémorale, artère carotide, vaisseaux utéro-placentaires) et fœtaux (artère ombilicale) avant et après exercice. Treize femmes en bonne santé, avec une grossesse sans complication (ainsi que l'issue) ont participé à l'étude entre la 36ème et la 40ème semaine de gestation. Chaque patiente a subi 5 tests d'effort en position assise sur une bicyclette ergométrique avec une charge de travail de 100 watts pendant 3 minutes.

Les examens doppler ont été réalisés avec un Acuson 128. Au niveau des artères fémorales et carotides, on a mesuré les pics de vélocité (systeolique et de fin de diastole et pour l'artère fémorale post systolique également), ainsi que les flux moyens. On a mesuré également les flux moyens au niveau de la veine fémorale. On a utilisé la technique du mode M pour la mesure des diamètres artériels, et la technique du mode B pour la mesure des diamètres de la veine fémorale. On a analysé les ondes de flux sanguins utéroplacentaires et ombilicaux à l'aide des indices de résistance et de pulsatilité.

La fréquence cardiaque maternelle ainsi que les pressions sanguines systoliques et diastoliques s'élèvent après chacun des tests d'effort. La vélocité sanguine moyenne s'élève au niveau de l'artère et de la veine fémorale alors que les diamètres des vaisseaux demeurent constants. Toutefois, au niveau de l'artère carotide, la vélocité demeure constante. L'analyse des ondes de vélocité au niveau de l'artère fémorale montre une élévation des vélocités systoliques et de fin de diastole ainsi qu'une inversion du flux post-systolique, alors que la vélocité est négative à l'état de repos. Il n'y a pas de modification au niveau des ondes de vélocité utéro-placentaires. Au niveau de l'artère carotide, on observe une augmentation des résistances et au niveau de l'artère ombilicale une diminution.

L'exercice physique entraine une redistribution des flux sanguins. Le débit sanguin s'élève au niveau des muscles actifs aux dépens des organes internes. Au cours des expérimentations animales, le débit sanguin utéro-placentaire diminue pendant l'exercice. Toutefois dans notre étude, on n'a pas trouvé de modification au niveau de la circulation utéro-placentaire bien qu'il y ait une élévation aigüe du débit sanguin au niveau des extrémités inférieures. L'absence de tout changement du rythme cardiaque fœtal et des ondes de vélocité sanguine ombilicale indique qu'il n'y a pas de risque pour le fœtus. En résumé, on peut dire qu'on n'a pas noté d'effets nocifs sur la circulation fœtale et utéroplacentaire au cours de l'exercice physique modéré a cours des grossesses non compliquées.

Mots-clés: Echographie Doppler, exercise, foetus, grossesse, mère.

Acknowledgements: We thank Mrs. B. Benz for her great help with this project. This study was supported by the Swiss National Science Foundation.

References

[1] Artal R, LD Platt, M Sperling, RK Kammula, J. Jilek, R Nakamura: Exercise in pregnancy. I. Maternal cardiovascular and metabolic responses in normal pregnancy. Am J Obstet Gynecol 140 (1981) 123

[2] Astrand PO, I Ryhming: A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. J Appl Physiol 7 (1954) 218

[3] Baumann H, P Kirkinen, R Mueller, B Schnarwyler, A Huch, R Huch: Blood flow velocity waveforms in large maternal and uterine vessels throughout pregnancy and postpartum: A longitudinal study using duplex sonography. Br J Obstet Gynaecol 95 (1988) 1282

[4] Bevegard BS, JT Shephard: Changes in tone of limb veins during supine exercise. J Appl Physiol 20 (1965) 1

[5] Campbell S, DR Griffin, JM Pearce, JD Diaz-Recasens, TE Cohen-Overbeek, K Willson: New Doppler technique for assessing uteroplacental blood flow. Lancet 1 (1983) 675

[6] Chandler KD, AW Bell: Effects of maternal exercise on fetal and maternal respiration and nutrient metabolism in the pregnant ewe. J Dev Physiol 3 (1981) 161

[7] Clapp JF: Acute exercise stress in the pregnant ewe. Am J Obstet Gynecol 136 (1980) 489

[8] Collings C, LB Curet: Fetal heart rate response to maternal exercise. Am J Obstet Gynecol 151 (1985) 498

[9] Curet LB, JA Orr, JHG Rankin, T Ungerer: Effect of exercise on cardiac output and distribution of uterine blood flow in pregnant ewes. J Appl Physiol 40 (1976) 725

[10] Emmanouilides GC, CJ Hobel, K Yashiro, G Klyman: Fetal responses to maternal exercise in the sheep. Am J Obstet Gynecol 112 (1972) 130

[11] Erskine RLA, JWK Ritchie: Umbilical artery blood flow characteristics in normal and growth retarded fetuses. Br J Obstet Gynaecol 92 (1985) 605

[12] Gill RW: Measurement of blood flow by ultrasound: Accuracy and sources of error. Ultrasound in Med & Biol 11 (1985) 625

[13] Globus M, E Melamed, A Keren, et al: Effect of exercise on cerebral circulation. J Cerebral Blood Flow and Metab 3 (1983) 287

[14] Gosling RG, DH King: Ultrasonic angiology. In: Harcus AW, L Adamson (eds): Arteries and Veins. Edinburgh: Churchill Livingstone (1975) 61

[15] Greenleaf JE, VA Convertino, RW Strempel, et al: Plasma (Na^+), (Ca^{2+}), and volume shifts and thermoregulation during exercise in man. J Appl Physiol 43 (1977) 1026

[16] Griffin D, T Cohen-Overbeek, S Campbell: Fetal and uteroplacental blood flow. Clin Obstet Gynecol 10 (1983) 565

[17] Hedlund S, G Nylin, O Regnstroem: The behaviour of the cerebral circulation during muscular exercise. Acta Physiol Scand 54 (1962) 316

[18] Hohimer AR, JM Bissonnette, J Metcalfe, TA McKean: Effect of exercise on uterine blood flow in the pregnant Pygmy goat. Am J Physiol 246 (1984) 207

[19] Hytten FE: The effect of work on placental function and fetal growth. In: Chamberlain G (ed): Pregnant women at work. London: Macmillan (1984) 15

[20] Lotgering FK, RD Gilbert, LD Longo: Exercise responses in pregnant sheep: Oxygen consumption, uterine blood flow, and blood volume. J Appl Physiol 55 (1983) 834
[21] Lotgering FK, RD Gilbert, LD Longo: Exercise responses in pregnant sheep: Blood gases, temperatures, and fetal cardiovascular system. J Appl Physiol 55 (1983) 842
[22] Lotgering FK, RD Gilbert, LD Longo: Maternal and fetal responses to exercise during pregnancy. Physiol Rev 65 (1985) 1
[23] Mahler F, L Koen, KH Johansen, EF Bernstein, A Fronek: Postocclusion and postexercise flow velocity and ankle pressures in normals and marathon runners. Angiology 27 (1976) 721
[24] Makin GS: Velocity in the femoral vein. The effect of respiration, exercise and tilt on blood velocity in the femoral vein as detected by an ultrasonic technique. Angeiologie 21 (1969) 319
[25] Moore DH, JC Jarrett, PJ Bendick: Exercise-induced changes in uterine artery blood flow, as measured by Doppler ultrasound, in pregnant subjects. Am J Perinatol 5 (1988) 94
[26] Morris N, SB Osborn, HP Wright, A Hart: Effective uterine blood-flow during exercise in normal and pre-eclamptic pregnancies. Lancet 2 (1956) 481
[27] Orr J, T Ungerer, J Will, K Wernicke, LB Curet: Effect of exercise stress on carotid, uterine and iliac blood flow in pregnant and non-pregnant ewes. Am J Obstet Gynecol 114 (1972) 213
[28] Pijpers L, JW Wladimiroff, J McGhie: Effect of short-term maternal exercise on maternal and fetal cardiovascular dynamics. Br J Obstet Gynaecol 91 (1984) 1081
[29] Pourcelot L: Applications cliniques de l'examen Doppler transcutane. In: Peronneau P (ed): Ultrasonic Doppler velocimetry INSERM 34 (1974) 213
[30] Rauramo I, B Andersson, T Laatikainen: Stress hormones and placental steroids in physical exercise during pregnancy. Br J Obstet Gynaecol 89 (1982) 921
[31] Rittenhouse EA, W Maixner, JW Burr, RW Barnes: Directional arterial flow velocity: A sensitive index of changes in peripheral vascular resistance. Surgery 79 (1976) 350
[32] Rowell LB: Human cardiovascular adjustments to exercise and thermal stress. Physiol Rev 54 (1974) 75
[33] Scheinberg P, LI Blackburn, M Rich, M Saslaw: Effects of vigorous physical exercise on cerebral circulation and metabolism. Am J Med 16 (1954) 549
[34] Steegers EAP, G Buijnk, RA Binkhorst, HW Jongsma, PFF Wijn, PR Hein: The influence of maternal exerise on the uteroplacental vascular bed resistance and the fetal heart rate during normal pregnancy. Eur J Obstet Gynecol Reprod Biol 27 (1988) 21
[35] Sutton MF, ER Greene, E Johnson, PA Reilly: Noninvasive echo-Doppler duplex measurements of common femoral artery blood flow variables during supine exercise and post-occlusive reactive hyperemia. ISA Transactions 22 (1983) 47
[36] Thompson RE, BJ Trudinger, CM Cook: A comparison of Doppler ultrasound waveform indices in the umbilical artery — I. Indices derived from the maximum velocity waveform. Ultrasound in Med & Biol 12 (1986) 835
[37] Ueland K, MJ Novy, EN Peterson, J Metcalfe: Maternal cardiovascular dynamics. IV. The influence of gestational age on the maternal cardiovascular response to posture and exercise. Am J Obstet Gynecol 104 (1969) 856
[38] Zobl EG, FN Talmers, RC Christensen, LJ Baer: Effect of exercise on the cerebral circulation and metabolism. J Appl Physiol 20 (1965) 1289

Received May 17, 1989. Accepted June 23, 1989.

Dr. Hans Baumann
Universitäts-Frauenklinik
Frauenklinikstraße 10
CH-8091 Zürich
Switzerland